Chalmers Publication Library

CHALMERS

Copyright Notice

(Article begins on next page)

A broadband THz waveguide-to-suspended stripline loop-probe transition

Johanna Hanning[1], Vladimir Drakinskiy[1], Peter Sobis[2], Tomas Bryllert[1], and Jan Stake[1]

[1]Chalmers University of Technology, 412 96 Gothenburg, Sweden

[2]Omnisys Instruments, 421 32 Västra Frölunda, Sweden

***Abstract*—We present a novel waveguide-to-suspended stripline loop-probe transition operating over the entire WR-1.0 waveguide band. The loop probe is designed for broadband response with simulated RL > 15 dB, and has an integrated DC return path, which can also be extended for biasing. The measured insertion loss for a back-to-back configuration is 1 – 2 dB in almost the entire frequency range of 750 – 1100 GHz.**

***Index Terms*—Terahertz electronics, THz, waveguide transition, loop probes, submillimeter wave integrated circuits, submillimeter wave devices.**

I. INTRODUCTION

Circuits at terahertz frequencies, such as multipliers and mixers, are usually based on semiconductor substrates which are integrated into a waveguide block [1]. The signals are coupled to the active devices via planar circuits, such as microstrip or membrane-based suspended stripline circuits, which are monolithically integrated on the same substrate as the device. This introduces the need for a broadband low loss transition between the rectangular waveguide and the planar circuit. For use with active devices, it is also beneficial if the transition includes a DC/IF return path to ground or bias connected circuitry, without compromising the bandwidth.

To date, the most common way to couple the THz signal between an input waveguide and a planar circuit is by an E-field probe, since that is readily incorporated in the E-plane waveguide split block technology. The probe couples to the E-field of the TE_{10} mode through the broad side of the waveguide wall. The circuit is then often extended beyond the probe with a high impedance line to the opposing wall of the waveguide, where it connects to ground or a bias choke filter [2]. The bandwidth of the transition can be increased by reducing the waveguide height as in [3], or by including matching elements in the waveguide, such as a capacitive step [4, 5]. At THz frequencies, however, where the waveguide milling tolerances are only a fraction of the wavelength, these structures may be difficult to achieve with the necessary accuracy. Matching waveguide elements may also prompt stricter mounting tolerances for the planar circuit.

Another option for coupling the signal, is by extending the center conductor into the waveguide in a loop that couples to the H-field of the TE_{10} mode. Loop-probe transitions are typically end-launched coaxial-to-waveguide transitions [6], but have also been presented with co-planar waveguide (CPW) [7]. The loop probe can be kept electrically small to increase the bandwidth. Another advantage is that a return path to ground is

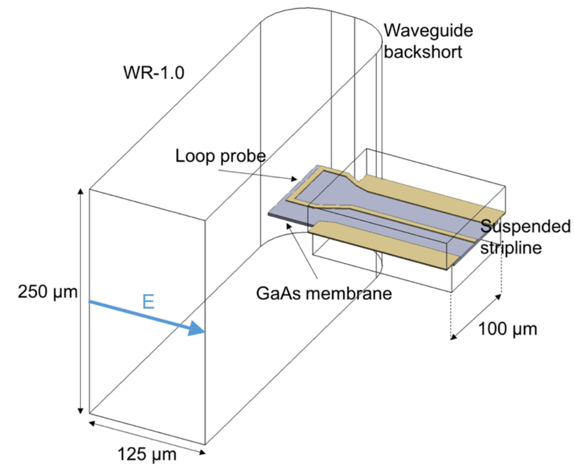

Fig. 1. Schematic of the proposed waveguide-to-suspended stripline transition. The input waveguide dimensions are standard WR-1.0 (250 µm × 125 µm), and the stripline is supported by a 3 µm GaAs membrane.

inherently included in the loop, since it connects to the waveguide wall. Although in use at low frequencies, this is yet to be presented at THz.

In this paper we present a waveguide-to-suspended strip line loop-probe transition in E-plane split block technology, operating over the full WR-1.0 waveguide band (0.75 – 1.1 THz), see Fig. 1. It couples to both E- and H-field, and provides a DC return path to ground at the end of the loop, eliminating the need to extend the planar circuit across the waveguide. We also demonstrate a loop probe with a bias line incorporated on the membrane. The suspended stripline circuit after the transition then becomes independent of the DC bias circuitry. Since the loop-probe is designed in full waveguide height, without matching elements in the waveguide, ease of manufacturing and consequently repeatability is increased. The probe is characterized in a back-to-back setup for measuring S-parameters at 0.75 – 1.1 THz, to verify the design.

II. DESIGN AND 3D MODELING

The proposed waveguide-to-suspended stripline circuit transition (Fig. 1) consists of a standard WR-1.0 (WM250) waveguide E-plane split block. A smaller waveguide channel (100 µm × 60 µm), perpendicular to the input waveguide, houses the membrane carrying the suspended stripline circuit. For future purposes it is restricted in its design by a desire to

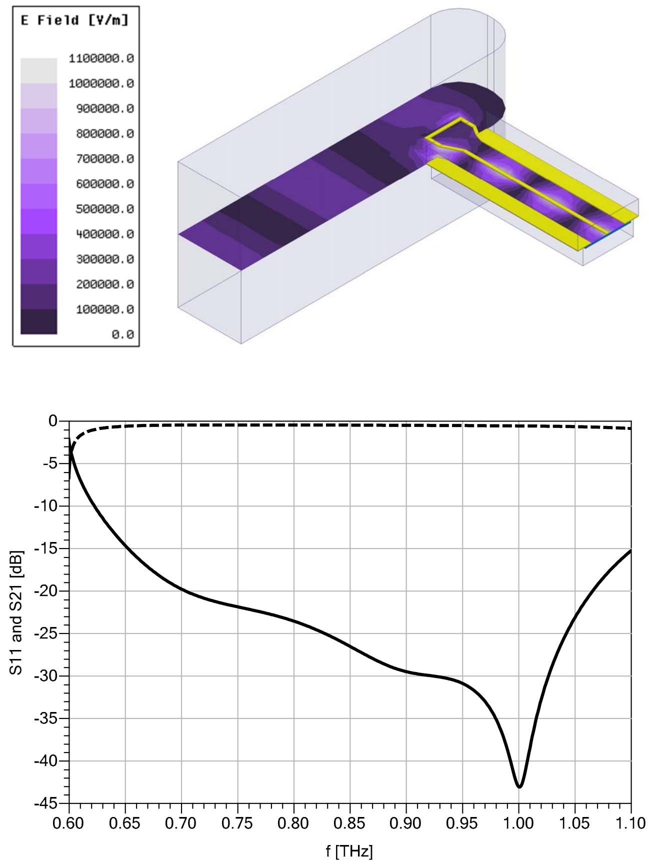

Fig. 2. (Top) Field plots of the simulated 3D waveguide-to-suspended stripline structure: Magnitude of the E-field in the E-plane split shows the coupled field at the center frequency. And vector plot in the waveguide shows the H-field coupling to the loop probe. (Bottom) Simulated S-parameters of the loop probe design show a return loss better than 15 dB for more than the entire waveguide band (0. 75 – 1.1 THz), and RL > 20 dB for 0.75 – 1.07 THz.

maximize the circuit channel width and height, single mode propagation, and maximum repeatability. The membrane is suspended in the channel by the use of metal beamleads, which are clamped between the two block halves. To minimize the effect of misalignment the beamleads extends the ground plane onto the membrane creating a hybrid CPW/coaxial mode, and the channel in the lid is made slightly wider than the bottom (+10 µm on each side).

A. Loop-probe design

The design is modeled using the finite element method in 3D to solve the electro-magnetic fields, using Ansoft HFSS.

The probe transition is designed in full waveguide height, with no additional matching structures in the waveguide. The conductor width is the same in the entire loop, and provide a characteristic impedance of 120 Ω on the suspended stripline. The center conductor enters the waveguide at roughly an E-field maximum, provide a broad side capacitive coupling to the opposing waveguide wall, and returns back to terminate at the beamlead which is closer to the waveguide backshort.

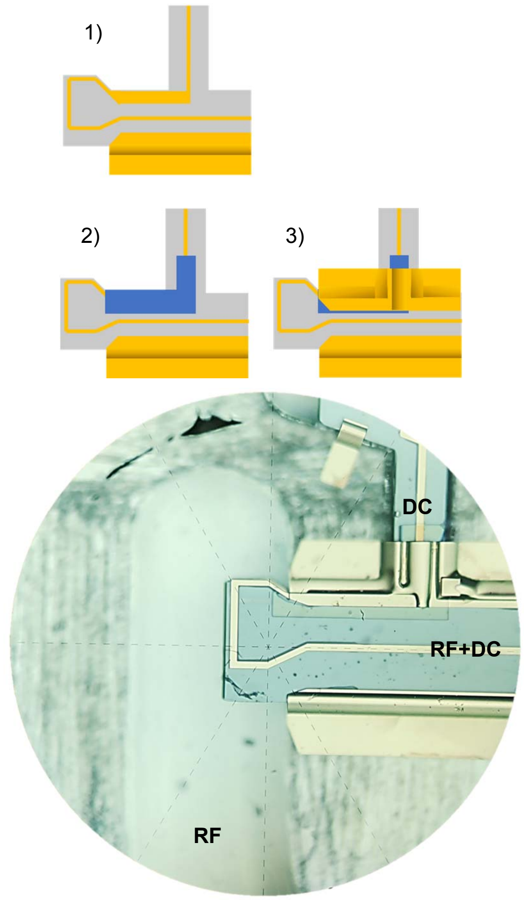

Fig. 3. (Top) Illustration of major process steps to form DC bias circuit and capacitor providing RF ground at the beamlead: 1) 1st metallization step, forming the circuit and one beamlead. 2) A 120 nm PECVD Si_3N_4 layer is deposited and patterned, providing the capacitor dielectric. 3) 2nd metallization step, forming top electrode/beamlead and air bridge over the DC bias line. (Bottom) Microscope photograph of the manufactured loop-probe waveguide-to-suspended stripline transition with DC bias connection, in the bottom half of the E-plane split block.

The resulting loop-probe can either be grounded at the beam lead for use as DC return path, or a capacitive dielectric layer between the beam lead and circuit can be used to provide an RF ground while connecting the probe end to DC bias.

The loop probe coupled to both the H- and E-fields as shown in Fig. 2 (Top). The simulated return loss (RL) is better than 15 dB for more than the entire waveguide band, 0.65 – 1.1 THz, and > 20 dB for 0.70 – 1.07 THz, see Fig. 2 (Bottom).

III. Circuit Fabrication

For comparison, two different prototype transitions have been manufactured: one with the loop probe directly grounded at the beamlead, and another including the dielectric layer and DC bias circuit. Both circuits are based on 3 µm GaAs membrane technology [8].

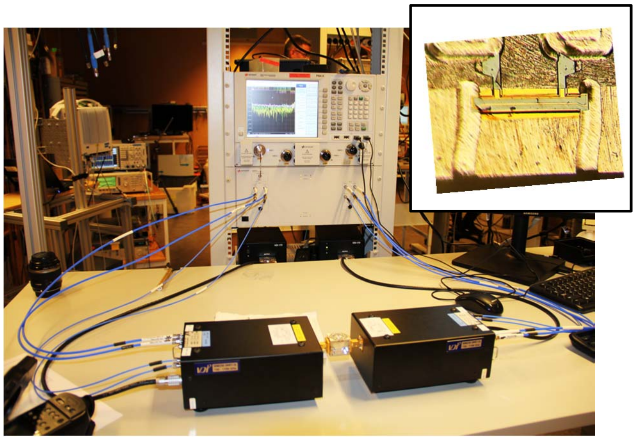

Fig. 4. (Large picture) THz S-parameter measurement setup. Keysight PNA-X, two VDI WR-1.0 frequency extenders, and adapter block locking the extenders in position and putting the two waveguide ports into the same flange at the top of the block. (Inset) Back-to-back patterned membrane circuit mounted inside the waveguide block for probe characterization.

For the probe including DC-bias circuitry, the membrane circuit process is extended to a 2-step circuit metal deposition process after active epi-layers have been removed, see Fig. 3. In an additional step a capacitive PECVD Si_3N_4 layer, which can double as passivation of finished active devices, is added between the two metallization layers.

The waveguide blocks are milled in aluminum with a tolerance of ±1–2 µm for each side of the waveguide structures.

The membrane circuits are picked and placed in the waveguide channel by hand to a mounting tolerance of ±5 µm sideways. The grounding beamleads are squeezed between the two block halves for a ground connection to the waveguide block.

IV. THz VNA Measurements

The probes are characterized in a back-to-back measurement setup and compared with simulations. The setup consists of a Keysight PNA-X with two WR-1.0 VNA frequency extenders from Virginia Diodes Inc. (VDI), see Fig. 4. Both frequency extenders are connected to an adapter block, which put each of the waveguide inputs into a single 2-port flange, similar to the setup we presented in [9]. By the use of this setup, measurement uncertainty due to extender cable flex is eliminated.

A built in variation of the SOLT calibration algorithm in the PNA-X, SSLT, is used to put the reference plane of the measurement in the 2-port flange. The calibration is performed with an in-house developed SSLT calibration kit, which consists of four different standards: A flush Short, a quarter-wavelength delay Short, a matched Load, and an unknown Thru. For the matched load, the load from the WR-1.0 calibration kit provided by VDI with the frequency extenders is used, with an additional waveguide adapter. The unknown thru standard is simply a horse-shoe shaped piece of waveguide, connecting the two ports using the shortest distance possible. At these frequencies getting well known calibration standards is difficult, and connection repeatability is a big issue [10]–[12]. In particular, it is difficult to provide a decent waveguide match load calibration, due to the large amount of reflections in the waveguide interfaces.

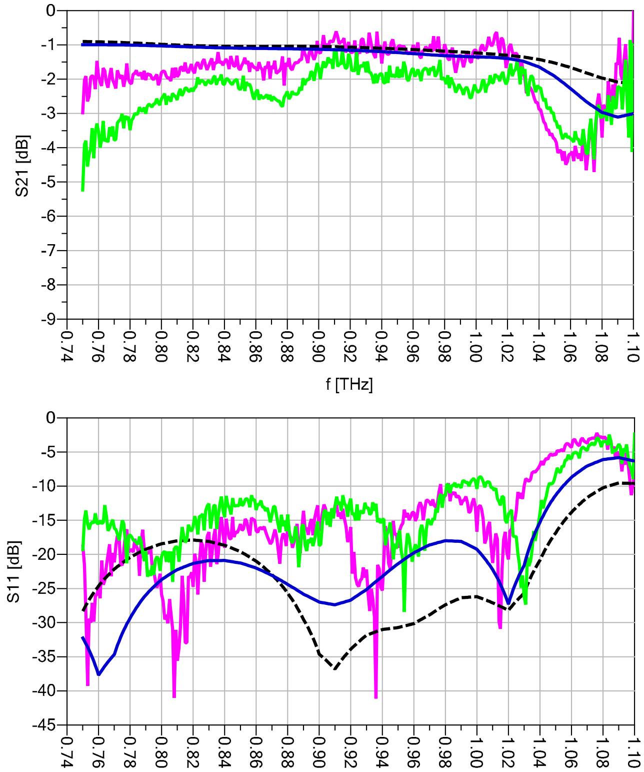

Fig. 5. Measured and simulated S-parameters of the waveguide-to-suspended stripline transition in the back-to-back setup. Black dashes: Ideal simulated result. Blue solid: Simulated result of misaligned circuit. Magenta solid: Grounded loop probe without DC bias. Green solid: Loop probe with DC bias included.

V. Results

The back-to-back measurements of the two loop-probe versions are compared to simulations in Fig. 5. The simulated response for both the well aligned, and a misaligned circuit is shown for comparison.

For the probe without bias line in a back-to-back configuration the insertion loss is as good as 1 dB in the center of the waveguide band, but increases to almost 4.5 dB above 1.04 THz. The IL is about 1 dB higher for the loop probe with DC bias circuit. However, under the microscope it looks as though the circuit is slightly misaligned, about 5 µm away from the waveguide backshort. The simulation results for the corresponding misalignment seem to be in good agreement with the measured result.

The measured S_{11} is not as good as the simulated, with almost a 10 dB difference for some frequencies. This may be due to the difficulty in achieving a good calibration.

VI. Conclusion

A broadband full waveguide height waveguide-to-stripline transition based on a grounded loop-probe structure providing an optional DC ground return and bias capability has been demonstrated. Simulated RL > 15 dB, and the measured insertion loss for a back-to-back configuration is 1 – 2 dB in almost the entire frequency range of 0.75 – 1.1 THz.

Further analysis on the repeatability of the probe design and S-parameter measurements is needed.

Acknowledgment

We would like to thank Mats Myremark and Dr. Jörgen Stenarson at the Department of Microtechnology and Nanoscience for the high precision machining of the waveguide blocks, and the aid in setting up the THz S-parameter measurements, respectively. This research was carried out in a joint research project financed by the Swedish Governmental Agency for Innovation Systems (VINNOVA), Chalmers University of Technology, Omnisys Instruments AB, Wasa Millimeter Wave AB, Low Noise Factory, and RISE Research Institutes of Sweden AB.

References

[1] T. W. Crowe, W. L. Bishop, D. W. Porterfield, J. L. Hesler, and R. M. Weikle II, “Opening the terahertz window with integrated diode circuits,” *IEEE Journal of Solid-State Circuits,* vol. 40, no. 10, pp. 2104-2110, 2005.

[2] C. Risacher, V. Vassilev, A. Pavolotsky and V. Belitsky, “Waveguide-to-microstrip transition with integrated bias-T,” *IEEE Microwave and Wireless Components Letters,* vol. 13, no. 7, pp. 262-264, 2003.

[3] S. C. Shi and J. Inatani, “A waveguide-to-microstrip transition with a DC-IF return path and an offset probe,” *IEEE Microwave Theory and Techniques*, vol. 45, no. 3, pp. 442-446, 1997.

[4] T. J. Reck, L. Chen, C. Zhang, A. Arsenovic, C. Groppi, A. Lichtenberger, R. M. Weikle II, and N. S. Barker, “Micromachined probes for submillimeter-wave on-wafer measurements—Part II: RF design and characterization,” *IEEE Transactions on Terahertz Science and Technology*, vol. 1, no. 2, pp. 357–363.

[5] M. F. Bauwens, N. Alijabbari, A. W. Lichtenberger, N. S. Barker and R. M. Weikle, “A 1.1 THz micromachined on-wafer probe,” in *IEEE MTT-S International Microwave Symposium (IMS)*, Tampa, FL, 2014.

[6] B. N. Das and G. S. Sanyal, “Coaxial-to-waveguide transition (end-launcher type),” presented at *the Proceedings of the Institution of Electrical Engineers – London*, 1976.

[7] R. N. Simons and S. R. Taub, “New coplanar waveguide to rectangular waveguide end launcher,” *Electronics Letters*, vol. 28, no. 12, pp. 1138–1139, 1992.

[8] H. Zhao, V. Drakinskiy, P. Sobis, J. Hanning, T. Bryllert, A. Y. Tang, and J. Stake, “Development of a 557 GHz GaAs monolithic membrane diode mixer,” *2012 International Conference on Indium Phosphide and Related Materials*, Santa Barbara, CA, 2012, pp. 102-105.

[9] J. Hanning, J. Stenarson, K. Yhland, P. Sobis and J. Stake, “Single-flange 2-port TRL calibration for accurate THz S-parameter measurements of waveguide integrated circuits,” *IEEE Transactions on Terahertz Science and Technology,* vol. 4, no. 5, pp. 583-587, 2014.

[10] D. F. Williams, “500 GHz–750 GHz rectangular-waveguide vector-network-analyzer calibrations,” *IEEE Transactions on Terahertz Science and Technology,* vol. 1, no. 2, pp. 364–377, Nov. 2011.

[11] N. M. Ridler and R. G. Clarke, “Further investigations into connection repeatability of waveguide devices at frequencies from 750 GHz to 1.1 THz,” presented at *the 83rd ARFTG Microwave Measurement Conference*, 2014, pp. 1–7.

[12] H. Li, A. Arsenovic, J. L. Hesler, A. R. Kerr, and R. M. Weikle II, “Repeatability and mismatch of waveguide flanges in the 500-750 GHz band,” *IEEE Transactions on Terahertz Science and Technology*, vol. 4, no. 1, pp. 39–48, Jan. 2014.